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NAST-I and SNPP Field Campaign Experience

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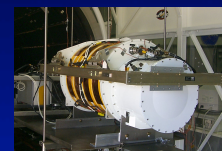
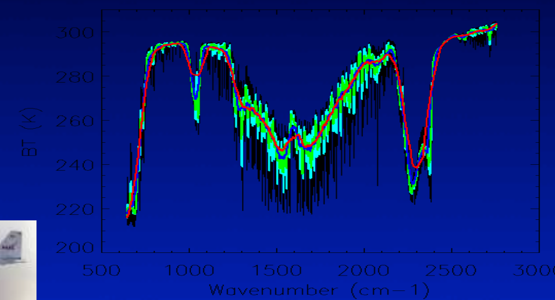
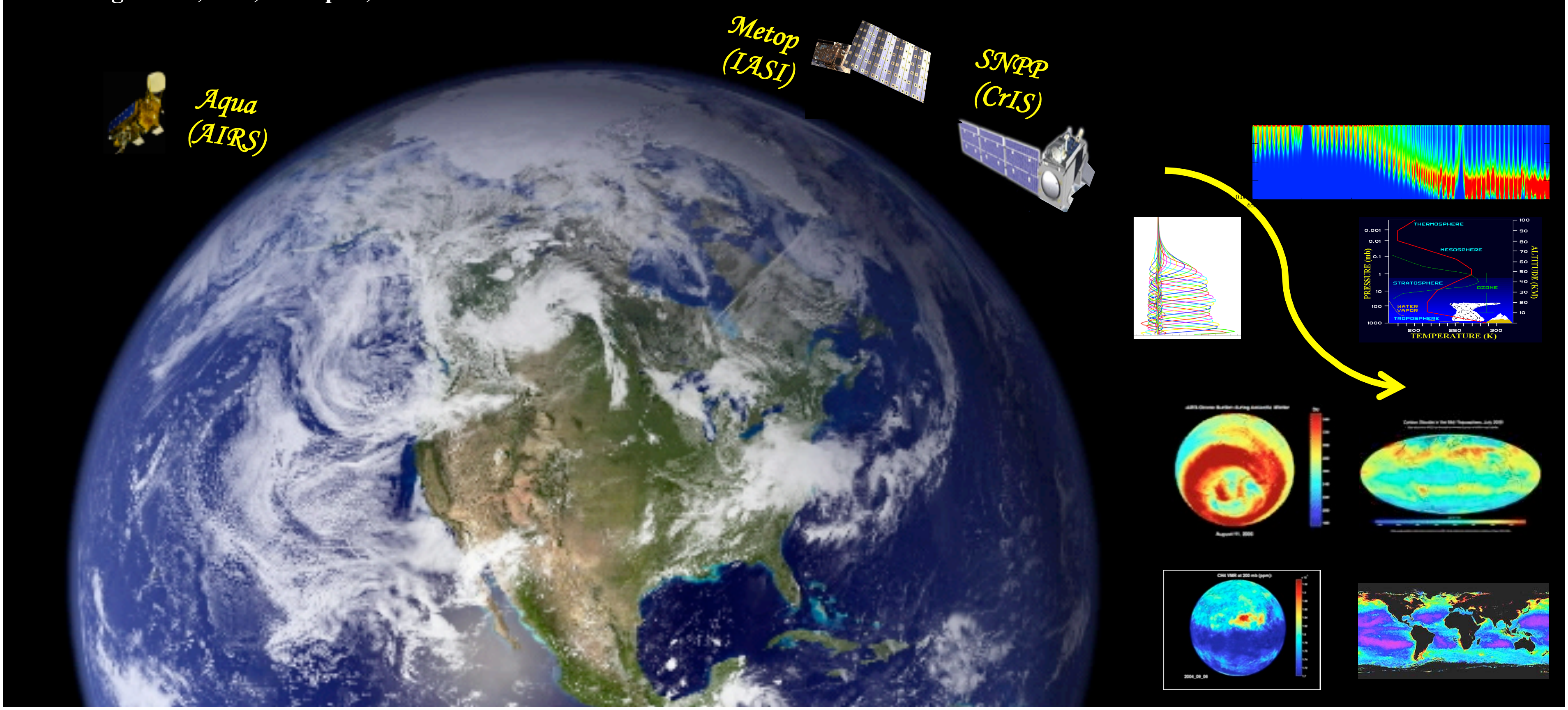




GOES-R Field Campaign Workshop
College Park, MD, 8-9 April, 2015



Topics

- **Airborne Campaigns**
  - –Cal/Val benefits
  - –NAST-I contributions
- **SNPP-1 Field Campaign**
  - –Palmdale, CA (May 2013)
- **SNPP-2 Field Campaign**
  - –Keflavik, Iceland (March 2015)
- **Key planning thoughts**

Key Cal/Val benefits from airborne campaigns

- Simultaneous independent, SI-traceable high spectral resolution radiance measurements for absolute **radiometric and spectral cal/val** of satellite sensors (i.e. provides absolute truth without relying on models)

- Space/time coincident observations enable **best method of inter-comparisons** with spaceborne measurements **in the presence of geophysical field spatial/temporal variability**

- **Transfer standard for cross-validation** of sensors in different orbits at more than a very limited range of polar latitudes (i.e., as provided by SNO approaches)

- Simultaneous independent in-situ and remotely sensed geophysical variables within the footprint of the satellite sounder to enable **validation of satellite direct/derived products and forward radiative transfer models** used for their derivation

- Higher spatial, spectral, and temporal resolution radiance measurements useful for **assessing impact of satellite sensor measurement characteristics on derived product accuracy**

- Redundancy of most critical measurements among campaign observation platforms (e.g., airborne IR FTS) ensures campaign success; **enables rapid internal-verification of satellite sensor and processing system performance**

⋮

NAST-I Program Overview

- **NAST-I is an airborne, x-track scanning IR FTS sounding system**
  - IR spectral radiance direct product; profiles of temperature, water vapor, trace species, surface and cloud properties for derived products
- **Significant campaign heritage in satellite measurement system cal/val (i.e., sensor, algorithms, and data products)**
  - High-altitude, airborne FTS systems (e.g. NAST-I, S-HIS) play a vital role by enabling traceable high-spectral-resolution comparisons with space/time coincident spaceborne measurements (validation & cross-validation)
- **LaRC NAST-I team is airborne cal-val centric, but impact is much broader**
  - Algorithm advancements & geophysical product retrievals infused into global programs (e.g., AIRS, IASI, & CrIS) and operational processing (e.g. NWP)
- **LaRC NAST-I team has end-to-end capability (measurement concept through results dissemination)**
  - Passive radiance measurements
  - Forward radiative transfer modelling
  - Geophysical product retrievals
  - Analysis & science studies
- **NAST-I is qualified and has had past missions on NASA ER-2, Proteus, and WB-57; DC-8 integration efforts underway in preparation for PECAN**
  - NADIR port 7 I&T in-progress

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NASA / NOAA Airborne Sounder Testbed - Interferometer (NAST-I) Overview

~ 180 mission sorties accumulating ~ 1000 hours of flight data in 20 field experiments
[e.g., CAMEX, C-IOP, WV-IOP, TRACE-P, IHOP, CRYSTAL-FACE, INTEX, EAQUATE, JAIVEx, SNPP, SNPP-2]

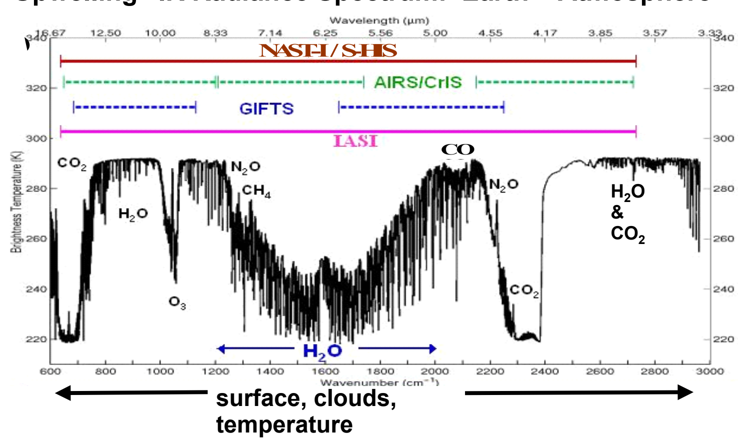
- ✓Validation tool
- ✓AQUA/SNPP/JPSS risk mitigation
- ✓Airborne science
- ✓Engineering testbed

IR Michelson Interferometer

Spectral range: 3.5 - 16 μ (630 – 2700 cm^{-1})
Spectral res.: 0.25 cm-1 ($\nu/\nu\delta$ > 2000)
Spatial res.: 130m/km flight alt. (2.6 km @ 20 km)
A/C platforms: ER-2, Proteus, WB-57, DC-8 (FY15)

Radiometric Measurement Capability
Radiances <0.5 K absolute accuracy, ~ 0.1 K precision

"Upwelling" IR Radiance Spectrum: Earth + Atmosphere



FY15 Campaigns

Main Objectives
- *Cal/Val for SNPP sensors (CrIS, ATMS, VIIRS), algorithms, and data products*
- Inter-platform comparisons between SNPP and legacy systems on MetOp and Aqua
- Advanced sounder science studies

SNPP-2

Purpose: continue SNPP validation with a specific focus on cold scene radiance spectra assessment and retrieval evaluation.

Aircraft: ER-2

Payload: NAST-I (LaRC), S-HIS (UW-Madison), NAST-M (MIT-LL), MASTER (AMES)

S/C under-flights: SNPP, Aqua, Metop-A, Metop-B

Base location: Keflavik, Iceland

Time period: ~ 7-31 March, 2015

Key Mission Objectives: Satellite under-flights over Greenland, over-flight of ground sites, collaborate with UK Met Office who will be basing their BAe 146 (fully instrumented with remote and in-situ sensors) flights out of Prestwick, UK and are also interested in some joint sorties over Greenland. Collaborate with ICECAPS (Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit) team.

PECAN

PECAN (Plains Elevated Convection at Night)

- **NAST-I & LASE on the NASA DC-8**
- **~ 3 weeks within June 1 - July 15, 2015**
- **US Southern Great Plains**

Project Description:

Multi-agency project (NSF, NOAA, NASA, DOE) designed to advance the understanding of continental, nocturnal, warm-season precipitation.

NAST-I Field Campaign Contributions

NAST-I DATA PRODUCT	CAMPAIGN RELEVANCE
Radiance • Infrared spectrum (3.5 – 16 μm) with 0.25 cm^{-1} spectral resolution. • Infrared spectral radiative heating/cooling information during aircraft ascents and descents. **Atmospheric Thermodynamics** • 3-d characterization of atmospheric state (temperature & moisture). • Profiles with vertical resolution of ~1-2 km for clear air or above clouds, vertical region dependent; horizontal resolution of < 130 m per km flight altitude **Atmospheric Composition** • Profiles in clear air or above clouds with vertical resolution of 2 – 10 km, depending on altitude and atmospheric constituent • Tropospheric CO and O_3 (PBL and free troposphere) from nominal flight altitude; other trace species (e.g., CO_2, CH_4, N_2O, and SO_2) also possible during platform ascents / descents. **Cloud Microphysical & Radiative Properties** • Effective top height, temperature, & spatial extent • Effective particle size & optical depth • Spectral emissivity **Surface Properties** • Temperature and spectral emissivity	**Science** • Temperature and trace species information helpful to characterize the boundary layer and free troposphere; contributes to weather, climate, air quality and biogeochemistry studies • Information on water vapor, ozone, cirrus clouds, and vertical profiles of infrared spectral radiance in the upper troposphere and lower stratosphere region beneficial for better understanding the radiative forcing of this region on climate system • Information on local meteorology, infrared heat budget, and trace gas evolution **Validation** • Contributes toward radiance and geophysical product validation, e.g., AIRS, IASI, CrIS • Inter-comparisons by spectral and spatial convolution to common resolution and coverage • High spatial resolution enables the effects of scene variability to be assessed **Future sensor studies** • Direct and derived NAST-I products contribute toward instrument specification and retrieval studies for future sensors, e.g., missions defined within the National Research Council Earth Science Decadal Survey (NRC DS)

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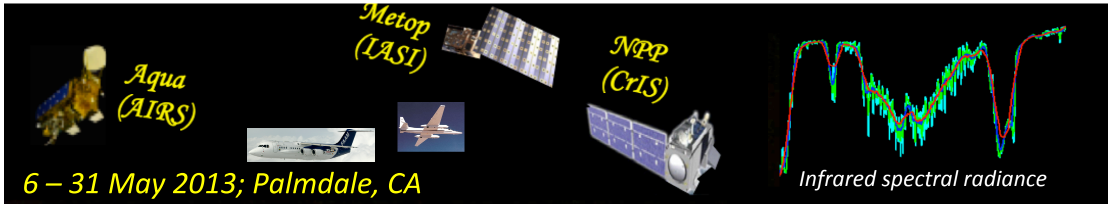
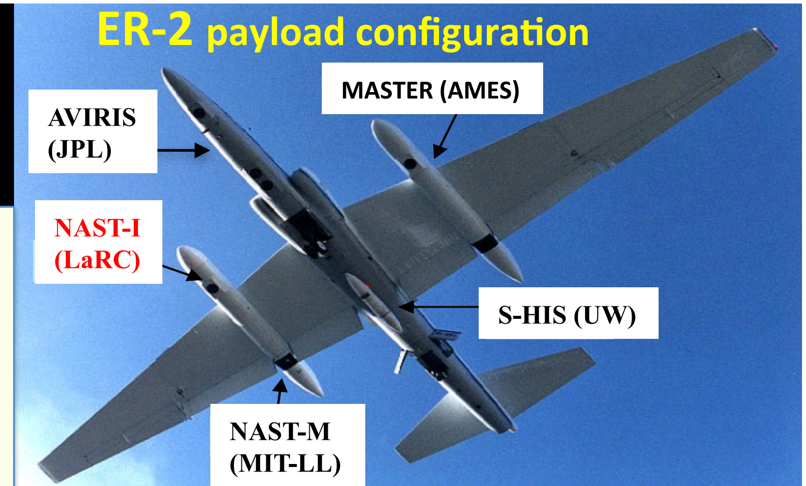
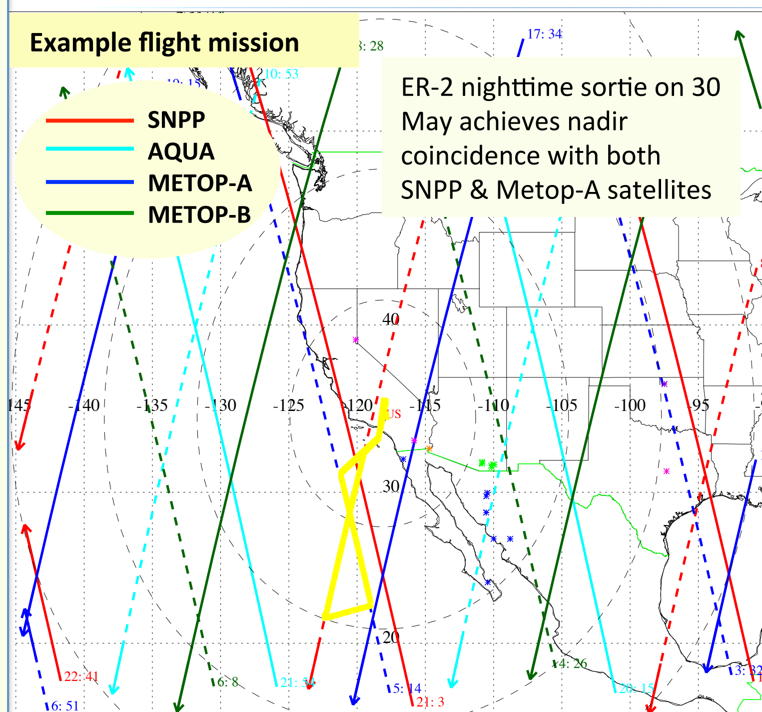
(NAST-I examples to follow from this campaign...)

Joint NASA / NOAA airborne field campaign in support of Suomi NPP (SNPP) cal/val (May 2013)





SNPP cal/val campaign sub-satellite tracks & ground sites: 5 / 30 (Thu)



Purpose:

- *Cal/Val for SNPP sensors (CrIS, ATMS, VIIRS), algorithms, and data products (SDRs & EDRs)*
- Inter-platform comparisons between SNPP sensors and legacy systems on MetOp and Aqua (e.g. CrIS vs IASI vs AIRS)
- Advanced sounder science studies (e.g. convective tendencies, surface characterization, retrievals and radiative transfer modeling)

Approach:

- ER-2 aircraft under-flights of SNPP, Aqua, MetOP-A, and MetOP-B satellites
- Over-flight of several instrumented calibration ground sites (i.e. Salton Sea water site, DOE mobile site in Yuma, AZ; DOE CART site in Lamont, OK; NOAA, DOE, NGA measurements at the CarbonTracker tower in Moody, TX) including ground-based FTIR and radiosonde measurements
- Joint sorties with UK Met Office BAe146 aircraft based out of Tucson, AZ (fully instrumented with remote / in-situ sensors and dropsondes)

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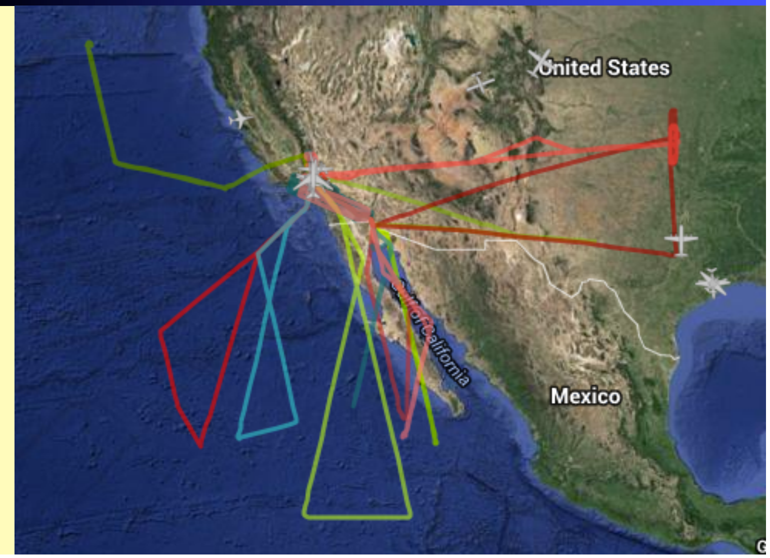
Suomi NPP (SNPP) 2013 cal/val campaign summary

Summary:

- Implemented 11 science flights, ~ 70 flight hours, over varying surfaces and meteorological scenes (i.e. water, land, clear, cloudy,…)
- All flights achieved satellite coincidence (8 at s/c nadir); 9 days had coincidence with multiple s/c in single flight; 3 night flights implemented
- Diplomatic clearance enabled flights over Mexican airspace (i.e. Gulf of California and Baja California)
- Convective stability tendency flight captured Moore, OK tornado on 20 May



Mission flights capture summary: Aircraft flight profile and key measurement asset coincidence

		S/C				A/C	GROUND				
GMT Date	Day / Night	SNPP	AQUA	METOPA	METOPB	BAE146	Yuma	Salton Sea	Moody	CART	Primary capture
5/7/13		x	x								pacific ocean; S/C nadir tracks
5/10/13		x									Clear over GOC & Pacific; SNPP nadir
5/15/13		x	x								Clear over GOC; S/C nadir Pacific
5/16/13				x							Pacific & GOC; Metop-A nadir
5/18/13											Moody site overflight; SNPP & Aqua near nadir
5/20/13											CART and MOODY sites; Moore Tornado!
5/23/13		x	x								Pacific; SNPP & Aqua nadir
5/24/13											CART site; precip in transit; SNPP near nadir
5/30/13		x		x							Pacific, clear air at night; SNPP & Metop-A nadir
5/31/13		x		x							Pacific and Baja CA at night; some clouds
6/1/13		x									GOC & Pacific at night; clear regions

Aircraft flight coincidence with measurement asset

x S/C nadir track coincidence

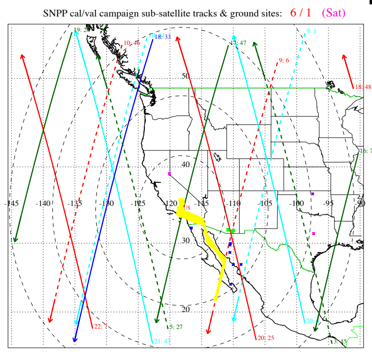
Langley Research Center **Example NAST-I products from SNPP campaign (2013)**

NAST-I vs SNPP CrIS: 1 June 2013 Flight

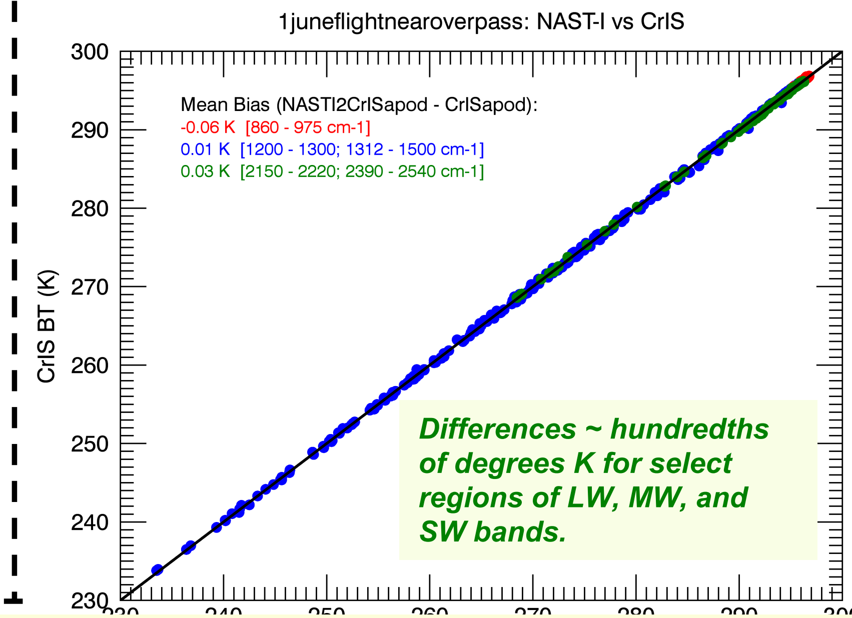
ER-2 nighttime sortie on 1 June achieves nadir coincidence with SNPP (0908 GMT); observes clear air over Pacific & GOC

Spectra compared for over water, near overpass time

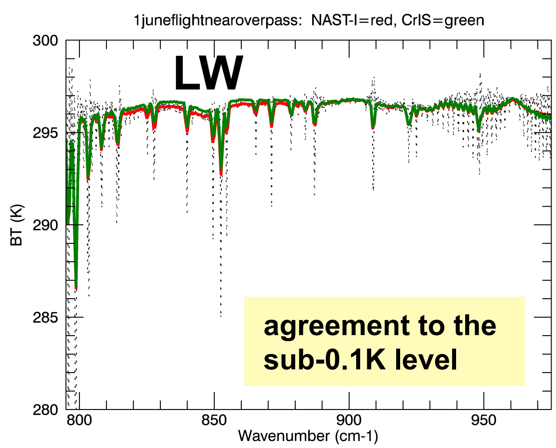
Key: spectra intercomparisons

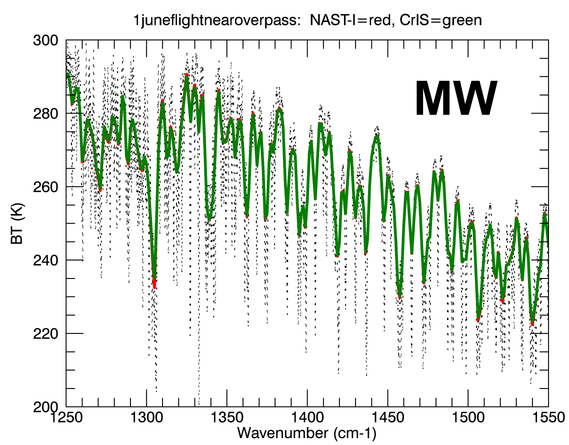


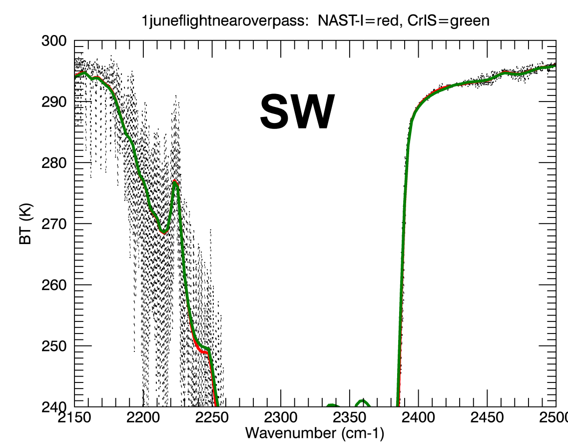
NAST-I (original) (dotted black)
NAST-I (degraded to apodized CrIS) (red)
CrIS (apodized) (green)



CrIS versus NAST-I average spectra. The higher-resolution NAST-I data have been reduced to the CrIS spectral resolution and spectra have been (Hamming) apodized to better facilitate radiometric calibration intercomparison.







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SNPP-2 Arctic Validation Campaign

Purpose: **continue SNPP validation with a specific focus on cold scene radiance spectra assessment and retrieval evaluation.**

Aircraft / Payload: ER-2/ NAST-I (LaRC), S-HIS (UW), NAST-M (LL), MASTER (AMES)

S/C under-flights: SNPP, Aqua, Metop-A, Metop-B

Base location / schedule: Keflavik, Iceland, **7-31 March, 2015**

Flight hours: ~ 52 hrs science, 75 hrs total; 6-10 mission flights

Key Mission Objectives: Satellite under-flights over Greenland, over-flight of Summit station ground site, collaborate with UK Met Office who based their BAe146 (fully instrumented with remote and in-situ sensors) flights out of Prestwick, UK and were also interested in some joint sorties over Greenland (conducted jointly from Keflavik). Collaborate with ICECAPS (Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit) team with over-flight of Summit Station, Greenland ground site.

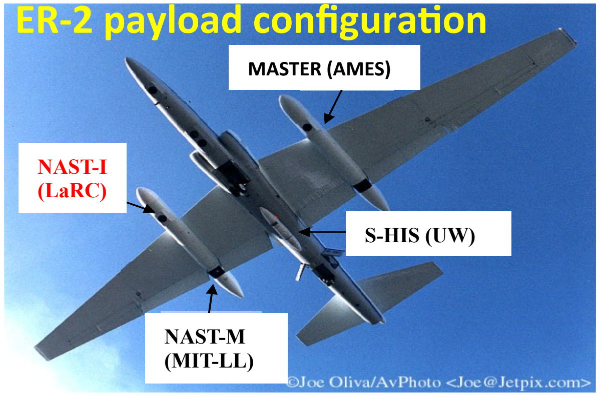
Specific mission goals include:

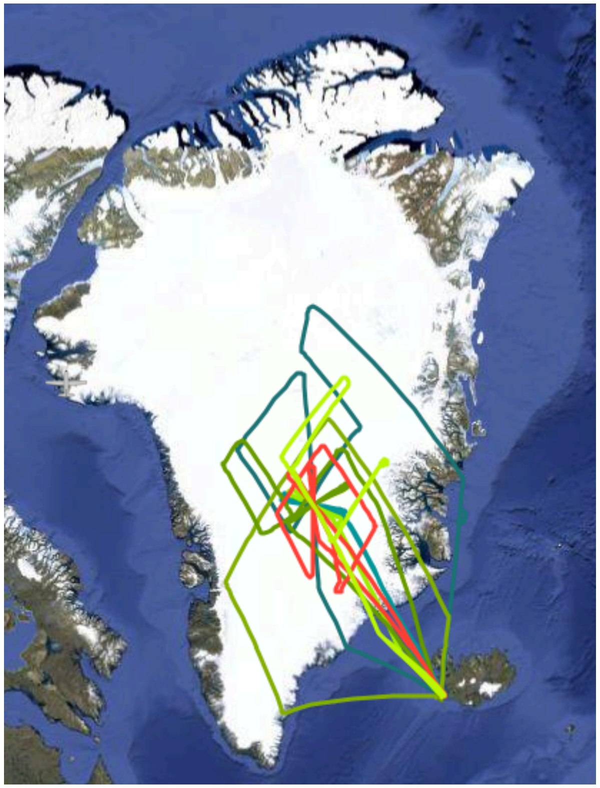
Cold scene satellite radiance assessment and retrieval evaluation.

- Assess CrIS and IASI radiance observations for very cold scenes (i.e. ~ 230K).
- EDR retrievals for such cold SDR spectra are quite challenging (e.g., complex snow, ice, cloud surface spatial distribution / emissivity non-uniformities and regions of limited vertical thermal contrast).

To provide "anchor points" for NWP data assimilation studies.

- Aircraft observations coincident with spacecraft sounder (CrIS, IASI, AIRS) overpasses and ground-based measurement assets (e.g. radiosondes) can provide closure datasets important for NWP data assimilation studies (i.e., independent SDRs, EDRs, and retrieved EDRs, for improving assimilation studies and corresponding error characterization).





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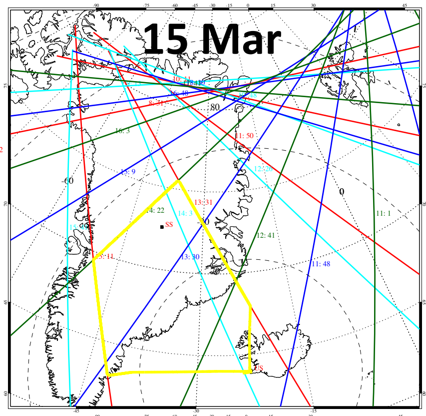
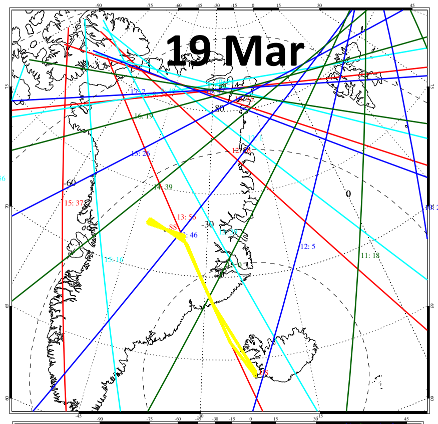
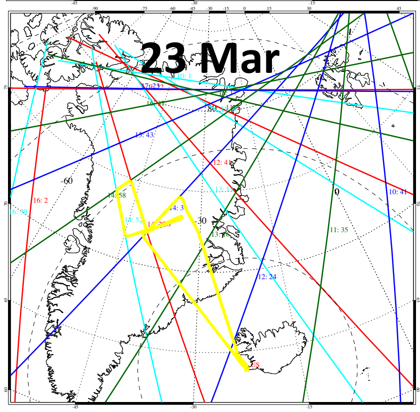
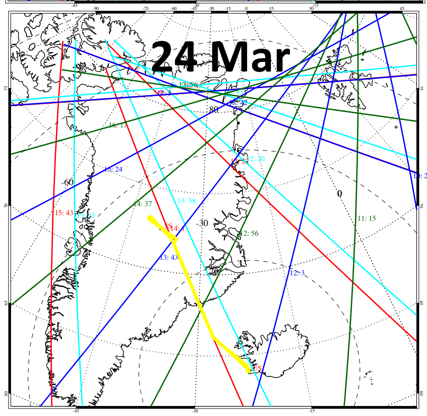
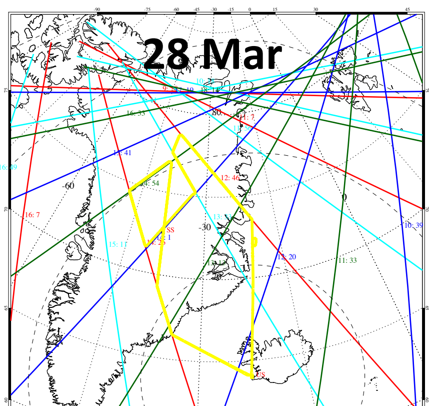
SNPP-2 campaign flight summary

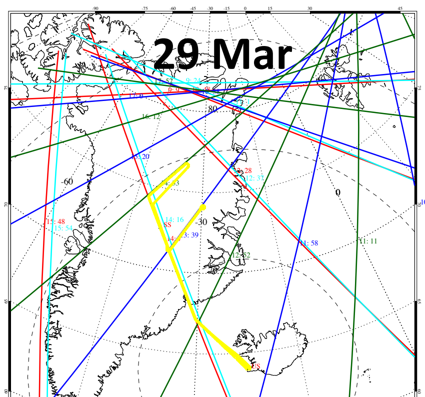




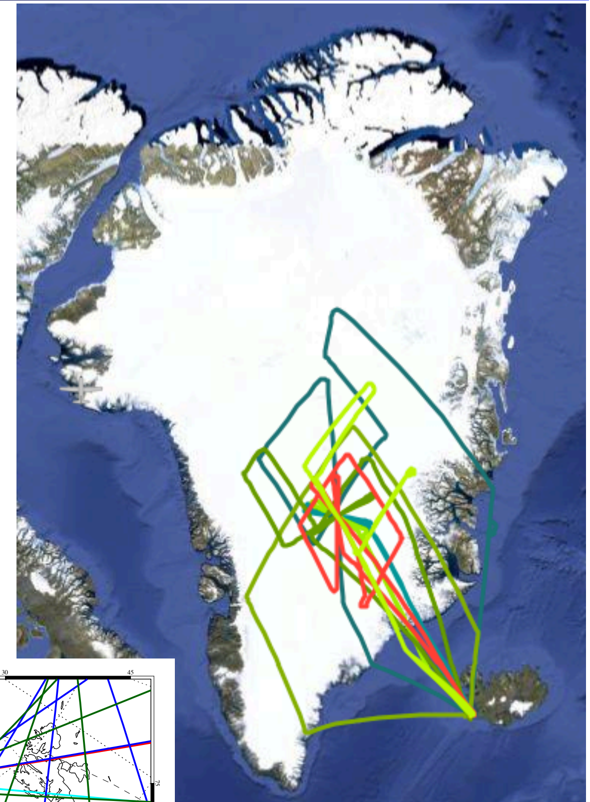




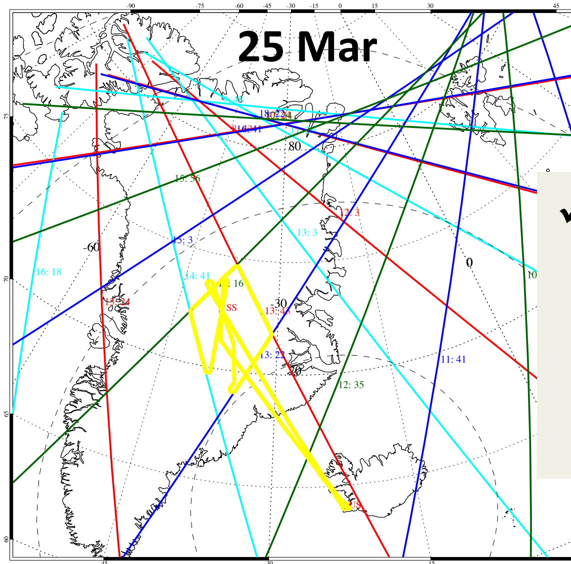




- ✓ 7 mission flights
- ✓ Repeated coincidence with SNPP, Aqua, Metop-A, Metop-B, Summit Station, BAe-146



SNPP
AQUA
METOP-A
METOP-B



- ✓ Some flights captured multiple assets for cross-validaton

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Key elements for planning/costing (1/2)

Needed campaign measurements → payload sensors, A/C platform, campaign location(s) & frequency, seasonal dependence, specific target scenes, correlative measurements and ground truth (ground, balloon, other a/c, and s/c), etc.

Some elements to be sure to include and cost…

For lead institution

Mission scientist

- Overall campaign planning, management, implementation; leads in-field flight plan formulation activities and serves as a liason between the various groups (flight crew, ground crew, instrument teams, etc.) to ensure mission science accomplished.
- Should activate > 1 year prior

For each instrument team:

Pre-field-phase

- Instrument & algorithm readiness costs
    - For sensor to become and/or retain flight readiness (i.e. campaign series)
    - Sensor calibration & characterization testing
    - Shipping to/from deployment site
    - Algorithm development, testing, and validation

In-field costs

- Travel expenses (airfare, per diem for hotel/meals, rental car) for deploying
- Staffing
- Expendables
- In-field data processing, analysis, inter-comparisons, and mission planning support

[Better to not only gather data but also have sufficient support to produce preliminary data products and first-order comparisons in-field to ensure optimum instrument performance and better resultant dataset. Not all such support has to be in-field, but portions should to optimize 24x7 flight operations in a different time zone.]

Key elements for planning/costing (2/2)

For each instrument team: (cont.)

Post-field-phase
- Sensor calibration & characterization testing
- Data processing, final dataset preparation and dissemination
- **Data Analysis!**

Aircraft & infrastructure costs

Flight hour costs (platform/year dependent)
  - ~ 50 – 80 mission flight hours per campaign, ~ 6-10 flights over ~ 3-4 week period is good baseline.
  - Include 4+ hours for a checkout flight; even if all sensors are pre-qualified on platform, still needed for a system-level test before campaign.
  - If deploying, must also add hours to enable round-trip ferry flights.

Mission peculiar costs (deployment of aircraft, flight and ground crew; overtime in support of non-standard duty day mission operations)
- ~ $150K to several hundred $K to deploy for a few weeks, depending on location and aircraft)

Facility costs (hangar, forklift, office/lab space, phone, internet, etc.—if deploying, base vs FBO differences)

Data archive & dissemination
  - While instrument teams will likely have their data archived at their home institutions, it is helpful to have a single location (i.e. one stop shop) for team members (as well as others in the community) to obtain campaign data. This could be as simple as a single website with links to instrument team data, readers, and documentation to all data being archived locally.

Meteorological product support
  - Provides past observations and future model fields for campaign domain
    - Target measurement variables & scene conditions
  - Greatly benefits flight option planning and Go / No-go decisions

Additional thoughts

- **Define what you can prior to in-field-phase**
  - Measurement objectives (prioritized), success criteria
  - Coincident observations (what, where, when?)
    - Ground sites, radiosondes, s/c tracks, other a/c & campaigns, ...
  - Draft a/c flight profiles, daily plan for coincidence (e.g. LEO s/c & other variable assets)
  - Go / no-go criteria (both target & payload), i.e. assuming local weather acceptable for a/c, define minimum science conditions and payload sensors required to warrant flight—usually based on many factors and varies as mission progresses, but good to consider in advance.

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Example pre-campaign flight planning

Define prioritized measurement objectives & needed coincident observations

SNPP-2 Cal/Val Campaign Flight Planning Matrix

ER-2 flight measurement objectives in support of SNPP SDR/EDR validation and related Arctic science

OBJECTIVES

ASSETS

S/C				A/C	GROUND						
SNPP	AQUA	METOPA	METOPB	BAE146	Summit	ICECAPS	Sondes	Ship	GIS	?	buoy?

DRAFT

Radiance validation
[cold, uniform scenes of varying T; land, ocean, snow, ice]
- o Clear sky night
- o Clear sky day
- o Clear sky over low-cloud
- o Clear sky over high-cloud

S/C sensor cross-validation
- o multiple S/C coincidence, i.e. SNPP + in single flight (CrIS vs IASI priority)

EDR/RT/NWP alg validation
[varying sfc and thermal contrast]
- o spatially uniform scenes
- o spatially non-uniform scenes
- o L2 ground truth
- o closure expt datasets

Sfc emissivity characterization
- o BAE146 low-level flight coincidence
- o ground-truth site(s), e.g. Summit
- o snow, ice, cloud, water

Meteorological focus areas
- o polar PBL
- o airmass evolution
- o isothermal atmosphere
- o thermal inversion
- o extreme cold layers (aviation safety)

Special issue investigation
- o sensor-unique, e.g. IASI-A vs IASI-B vs CrIS for scenes < 230K

Aircraft flight profiles defined to optimize satisfaction of key mission objectives relative to campaign constraints
- ○ Measurement objective(s) to be addressed, relative priority
- ○ Scene conditions (atmosphere, cloud, surface)
- ○ The availability and degree of coincidence for other observation assets (satellite, ground stations, radiosondes, buoys, other airborne measurements, etc.)

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- ○ Accomplishments thus far, remaining flight hours & campaign days, near-term forecasts, …

Assumptions:
> S/C coincidence planned for each flight
> A single flight can address multiple objectives
> Each flight plan will attempt to satisfy unaddressed measurment objectives (rows) while maximizing asset coincidence (columns)

12/17/14 DRAFT

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Pursue campaign leveraging…

UK Met Office FAAM BAe146-301

Facility for Airborne Atmospheric Measurements (FAAM)

Complement of remote sensing and in-situ instruments

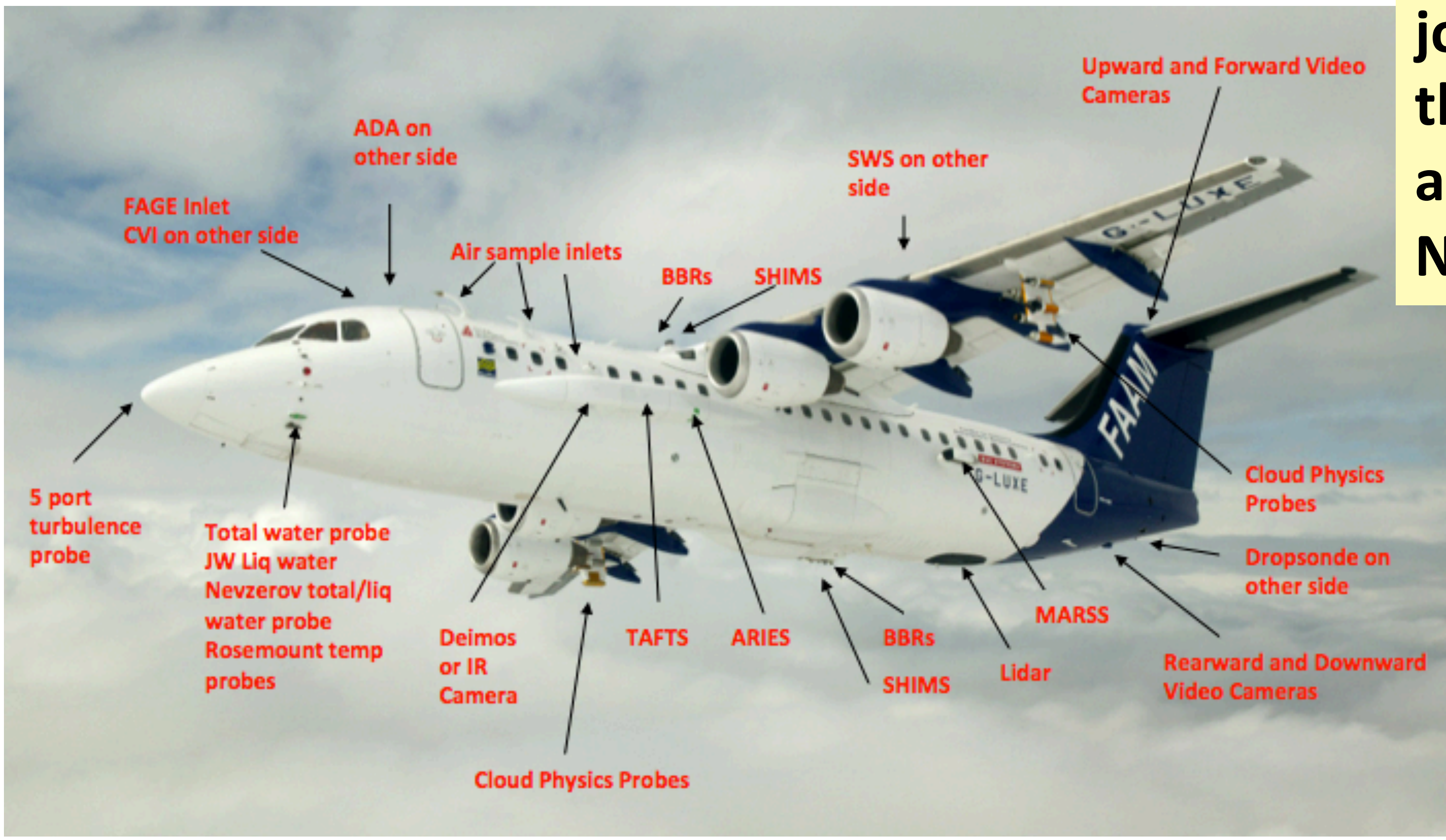
Dropsondes

In-situ CO, NOx, O3, CH4 CO2, SO2, cloud & aerosol properties

Lidar (O3, H2O)

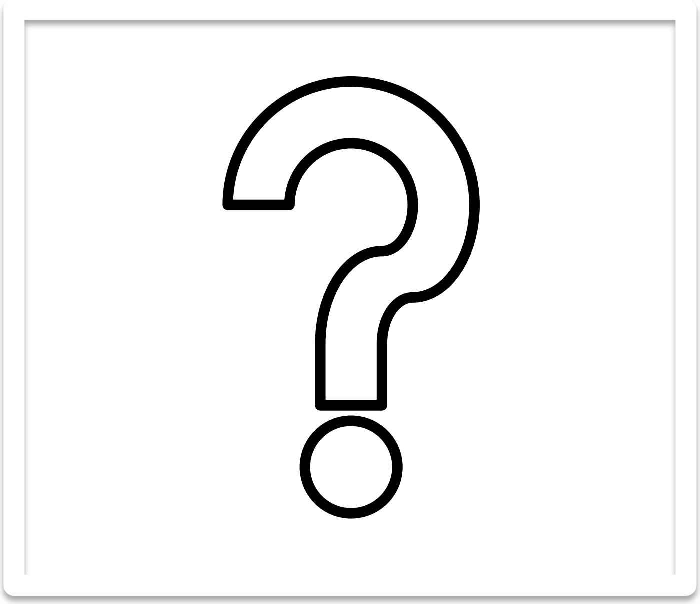
IR interferometer; Far-IR interferometer; Microwave Radiometer

Short wave spectrometer; Infrared radiometer; Infrared imager



For the Suomi NPP campaigns, we have teamed with the UK Met Office to conduct joint sorties with their BAe-146 aircraft and our NASA ER-2

Questions



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